Planck Oscillators and Elementary Particles

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Abstract

In this paper we argue that it is possible to model the Universe along thermodynamic lines, using oscillators in the background Dark Energy at the Planck scale. This leads to meaningful results in agreement with observation.

1 Introduction

In 1997 the author proposed a model in which elementary particles are created out of a background Dark Energy or Zero Point Field (ZPF). This predicted a cosmology in which the universe accelerates, driven by the Dark Energy, with a small cosmological constant. Moreover several supposedly inexplicable so called Large Number coincidences were all deduced from the above model (Cf.refs.[1, 2, 3]). At that time the prevailing model was the standard Big Bang in which, because of dark matter, the universe would be decelerating. However the work of Perlmutter and others confirm the cosmic acceleration and the small cosmological constant in 1998 itself (Cf. for example [4, 5, 6] and several references therein). Moreover in the new model there would be a residual energy that would be extremely small.

Let us first re-derive the recently discovered [7] residual cosmic energy directly from the background Dark Energy. We may reiterate that the "mysterious" background Dark Energy is the same as the quantum Zero Point Fluctuations in the background vacuum electromagnetic field .The background Zero Point Field is a collection of ground state oscillators [8]. The probability

amplitude is

$$\psi(x) = \left(\frac{m\omega}{\pi\hbar}\right)^{1/4} e^{-(m\omega/2\hbar)x^2}$$

for displacement by the distance x from its position of classical equilibrium. So the oscillator fluctuates over an interval

$$\Delta x \sim (\hbar/m\omega)^{1/2}$$

The background electromagnetic field is an infinite collection of independent oscillators, with amplitudes X_1, X_2 etc. The probability for the various oscillators to have amplitudes X_1, X_2 and so on is the product of individual oscillator amplitudes:

$$\psi(X_1, X_2, \cdots) = exp[-(X_1^2 + X_2^2 + \cdots)]$$

wherein there would be a suitable normalization factor. This expression gives the probability amplitude ψ for a configuration $B(x, y, z)$ of the magnetic field that is described by the Fourier coefficients $X_1, X_2, \cdots$ or directly in terms of the magnetic field configuration itself by, as is known,

$$\psi(B(x, y, z)) = Pexp\left(-\int\int \frac{\mathbf{B(x_1)} \cdot \mathbf{B(x_2)}}{16\pi^3 \hbar c r_{12}^2} d^3x_1 d^3x_2\right).$$

P being a normalization factor. At this stage, we are thinking in terms of energy without differenciation, that is, without considering Electromagnetism or Gravitation etc as separate. Let us consider a configuration where the field is everywhere zero except in a region of dimension l, where it is of the order of $\sim \Delta B$. The probability amplitude for this configuration would be proportional to

$$\exp[-((\Delta B)^2 l^4/\hbar c)]$$

So the energy of fluctuation in a region of length l is given by finally, the density mwt,nof [8, 6]

$$B^2 \sim \frac{\hbar c}{l^4}$$

So the energy content in a region of volume l^3 is given by

$$\beta^2 \sim \hbar c/l \qquad (1)$$ 4e1

This energy is minimum when l is maximum. Let us take l to be the radius of the Universe $\sim 10^{28} cms$. The minimum energy residue of the background Dark Energy or Zero Point Field (ZPF) alluded to now comes out

to be $10^{-33}eV$, exactly the observed value. This observed residual energy is a cosmic footprint of the ubiquitous Dark Energy in the Universe, a puzzling footprint that, as we have noted, has recently been observed [7]. The minimum mass $\sim 10^{-33}eV$ or $10^{-65}gms$, will be seen to be the mass of the photon. Interestingly, this also is the minimum thermodynamic mass in the Universe, as shown by Landsberg from a totally different point of view, that of thermodynamics [9].

If on the other hand we take for l in (1) the smallest possible length, which has been taken to the Planck length l_P, as we will see in the sequel, then we get the Planck mass $m_P \sim 10^{-5}gm$.

So (1) gives two extreme masses, the Planck mass and the photon mass. We will see how it is possible to recover the intermediate elementary particle mass from these considerations later.

As an alternative derivation, it is interesting to derive a model based on the theory of phonons which are quanta of sound waves in a macroscopic body [10]. Phonons are a mathematical analogue of the quanta of the electromagnetic field, which are the photons, that emerge when this field is expressed as a sum of Harmonic oscillators. This situation is carried over to the theory of solids which are made up of atoms that are arranged in a crystal lattice and can be approximated by a sum of Harmonic oscillators representing the normal modes of lattice oscillations. In this theory, as is well known the phonons have a maximum frequency ω_m which is given by

$$\omega_m = c \left(\frac{6\pi^2}{v}\right)^{1/3} \tag{2}$$

In (2) c represents the velocity of sound in the specific case of photons, while $v = V/N$, where V denotes the volume and N the number of atoms. In this model we write

$$l \equiv \left(\frac{4}{3}\pi v\right)^{1/3}$$

l being the inter particle distance. Thus (2) now becomes

$$\omega_m = c/l \tag{3}$$

Let us now liberate the above analysis from the immediate scenario of atoms at lattice points and quantized sound waves due to the Harmonic oscillations and look upon it as a general set of Harmonic oscillators as above. Then we

can see that (3) and (1) are identical as

$$\omega = \frac{mc^2}{\hbar}$$

So we again recover with suitable limits the extremes of the Planck mass and the photon mass.
Other intermediate elementary particle masses follow if we take l as a typical Compton wavelength.The Compton wavelength comes about, if we consider the entire Universe which has a volume of the order 10^{84} cc. to be made up of 10^{120} Planck Oscillators,as we will see.Then v in (2) turns out to be 10^{-36} and l becomes 10^{-12} cm – a typical Compton wavelength.
Max Planck had noticed that, what we call the Planck scale today,

$$l = \left(\frac{\hbar G}{c^3}\right)^{\frac{1}{2}} \sim 10^{-33} cm$$

$$m = \sqrt{\frac{\hbar c}{G}} \sim 10^{-5} gm$$

$$t = \sqrt{\frac{\hbar G}{c^5}} \sim 10^{-42} sec \tag{4}$$

is made up of the fundamental constants of nature and so, he suspected it played the role of a fundamental length [11]. Indeed, modern Quantum Gravity approaches have invoked (4) in their quest for a reconciliation of gravitation with other fundamental interactions. Indeed, as can be seen from (4), this scale combines the Gravitational constant G and classical theory with the Planck constant of Quantum theory. However if this is a fundamental scale, then the time honoured prescription of a differentiable spacetime has to be abandoned.
There is also another scale made up of fundamental constants of nature, viz., the well known Compton scale (or classical electron radius),

$$l = e^2/m_e c^2 \sim 10^{-12} cm \tag{5}$$

where e is the electron charge and m_e the electron mass. The Compton scale emerges from the ZPF. This had appeared in the Classical theory of the electron unlike the Planck scale, which was a product of Quantum Theory. Indeed if (5) is substituted for l in (1), we get the elementary particle mass

scale.
The scale (5) has also played an important role in modern physics, though it is not considered as fundamental as the Planck scale. Nevertheless, the Compton scale (5) is close to reality in the sense of experiment, unlike (4), which is well beyond foreseeable direct experimental contact. Moreover another interesting feature of the Compton scale is that, it brings out the Quantum Mechanical spin, unlike the Planck scale.
Let us investigate further from another point of view.

2 The Planck and Compton Scales

String Theory, Loop Quantum Gravity and a few other approaches start from the Planck scale. This is also the starting point in our alternative theory of Planck oscillators in the background dark energy. We first give a rationale for the fact that the Planck scale would be a minimum scale in the Universe [12]. Our starting point [13, 6] is the model for the underpinning at the Planck scale for the Universe. This is a collection of N Planck scale oscillators where we will specify N shortly.
Let us consider an array of N particles, spaced a distance Δx apart, which behave like oscillators that are connected by springs. We then have [14, 15, 16, 6]

$$r = \sqrt{N \Delta x^2} \tag{6}$$

$$ka^2 \equiv k\Delta x^2 = \frac{1}{2} k_B T \tag{7}$$

where k_B is the Boltzmann constant, T the temperature, r the extent and k is the spring constant given by

$$\omega_0^2 = \frac{k}{m} \tag{8}$$

$$\omega = \left(\frac{k}{m} a^2\right)^{\frac{1}{2}} \frac{1}{r} = \omega_0 \frac{a}{r} \tag{9}$$

We now identify the particles with Planck masses and set $\Delta x \equiv a = l_P$, the Planck length. It may be immediately observed that use of (8) and (7) gives

$$k_B T \sim m_P c^2,$$

which of course agrees with the temperature of a black hole of Planck mass. Indeed, Rosen [17] had shown that a Planck mass particle at the Planck scale can be considered to be a Universe in itself with a Schwarzchild radius equalling the Planck length. We now observe that if in (6), we take the extent r to be the radius of the universe $\sim 10^{27} cm$, then we get for N, the number of Planck oscillators underpinning the universe, $N \sim 10^{120}$, which we had assumed earlier. If we now use the well known fact that there are 10^{80} elementary particles in the universe then we conclude that $n \sim 10^{40}$ Planck oscillators underpin elementary particles [13, 14]. In any case, ultimately, the only parameter we will be using is the well known number of elementary particles in the universe $\sim 10^{80}$.
Using this in (6), we get $r \sim l$, the Compton wavelength $10^{-12} cm$ as required. Whence the elementary particle mass is given by

$$m = m_P/\sqrt{n} \sim 10^{-25} gm \tag{10}$$

This follows from (9), remembering that $\omega = mc^2/\hbar$. This shows that while the Planck frequency or energy is the highest, the energy of the $n \sim 10^{40}$ Planck oscillator array is lowest, so that this configuration is stable. In fact we recover from (10), the Compton wavelength (5) and Compton time of an elementary particle.
This explains why we encounter elementary particles, rather than Planck mass particles in nature. In fact as known [18], a Planck mass particle decays via the Bekenstein radiation within a Planck time $\sim 10^{-42} secs$. On the other hand, the lifetime of an elementary particle would be very much higher.
We now make two interesting comments. Cercignani and co-workers have shown [19, 20] that when the gravitational energy becomes of the order of the electromagnetic energy in the case of the Zero Point oscillators, that is

$$\frac{G\hbar^2\omega^3}{c^5} \sim \hbar\omega \tag{11}$$

then this defines a threshold frequency ω_{max} above which the oscillations become chaotic. In other words, for meaningful physics we require that

$$\omega \leq \omega_{max}.$$

Secondly as we saw from the parallel but unrelated theory of phonons [10, 21], which are also bosonic oscillators, we deduce a maximal frequency given by

$$\omega_{max}^2 = \frac{c^2}{l^2} \tag{12}$$

In (12) c is, as we saw in the particular case of phonons, the velocity of propagation, that is the velocity of sound, whereas in our case this velocity is that of light. Frequencies greater than ω_{max} in (12) are again meaningless. We can easily verify that using (11) in (12) gives

$$Gm_P^2 \sim \hbar c \sim \epsilon^2 \tag{13}$$

This is a well known relation expressing the equality of electromagnetic and gravitational interaction strengths at the Planck scale. Using (10) in (13), we can deduce that

$$Gm^2 \sim \epsilon^2/10^{40} \tag{14}$$

The relation (14) has been well known, though as an empirical relation expressing the relative strengths of the gravitational and electromagnetic strengths. Here we have deduced it on the basis of our theory.
The Compton scale (5) comes as a Quantum Mechanical effect, within which we have zitterbewegung effects and a breakdown of causal Physics as emphasized in the literature [22]. Indeed Dirac had noticed this aspect in connection with two difficulties with his electron equation. Firstly the speed of the electron turns out to be the velocity of light. Secondly the position coordinates become complex or non Hermitian. His explanation was that in Quantum Theory we cannot go down to arbitrarily small spacetime intervals, for the Heisenberg Uncertainty Principle would then imply arbitrarily large momenta and energies. So Quantum Mechanical measurements are actually an average over intervals of the order of the Compton scale.
Weinberg also noticed the non physical aspect of the Compton scale [23]. Starting with the usual light cone of Special Relativity and the inversion of the time order of events, he goes on to add, and we quote,
"Although the relativity of temporal order raises no problems for classical physics, it plays a profound role in quantum theories. The uncertainty principle tells us that when we specify that a particle is at position x_1 at time t_1, we cannot also define its velocity precisely. In consequence there is a certain chance of a particle getting from x_1 to x_2 even if $x_1 - x_2$ is spacelike, that is, $|x_1 - x_2| > |x_1^0 - x_2^0|$. To be more precise, the probability of a particle reaching x_2 if it starts at x_1 is nonnegligible as long as

$$(x_1 - x_2)^2 - (x_1^0 - x_2^0)^2 \leq \frac{\hbar^2}{m^2}$$

where $\hbar$ is Planck's constant (divided by 2π) and m is the particle mass."

3 Discussion

1. It may be mentioned that the Compton wavelength in the context of the background vacuum energy or Dark Energy, as we saw in (1) has the following important property [24]: The Coulomb self energy which is proportional to $1/a$ where a in which case is the Compton wavelength, exactly balances the vacuum energy, thus providing a stable configuration. In the old theory on the other hand, this was a major inconsistency– neither could the length a could be non zero nor could $a \to 0$ as the self energy would then diverge [25].
2. We can get a further insight into the array of Planck oscillators, following the earlier argument of Random fluctuational creation of such oscillators from the background Dark Energy, alluded to in the cosmological model at the beginning of Section 1. According to this Planck oscillators are randomly created and destroyed in the Dark Energy background. However, mimicking the Random Walk, there would be a nett creation of $\sqrt{n}$ Planck oscillators out of n total fluctuations in a time interval t_P, the Planck time, which in any case is very small and is nearly a continuum. So we have

$$\frac{dn}{dt} \approx \frac{\sqrt{n}}{t_P} \qquad (15)$$

Integrating (15) we get

$$t_\pi = \sqrt{n} t_P \,\text{or}\, l_\pi = \sqrt{n} l_P$$

which is just equation (6), giving $n \sim 10^{40}$, for the Compton time of an elementary particle like the pion.
On the other hand integrating up to the age of the universe

$$T \sim 10^{17},$$

we get

$$T = \sqrt{N} t_P,$$

giving $N \sim 10^{120}$. This gives a rationale for the values of n and N given above.
3. We can consider the above scenario from yet another point of view, that of Quantum Statistical Mechanics. Here also, in the spirit of randomness, the state can be written as [5, 10]

$$\psi = \sum_n c_n \phi_n, \qquad (16)$$

in terms of basic states ϕ_n representing a Planck oscillator with energy E_n it is known that (16) can be rewritten as

$$\psi = \sum_n b_n \bar{\phi}_n \qquad (17)$$

where $|b_n|^2 = 1$ if $E < E_n < E + \Delta$, and $= 0$ otherwise under the assumption

$$\overline{(c_n, c_m)} = 0, n \neq m \qquad (18)$$

(Infact n could stand for not a single state but for a set of states $n_\imath$ and so also m). Here the bar denotes a time average over a suitable interval. This is the well known Random Phase Axiom and arises due to the total randomness amongst the phases c_n. Also the expectation value of any operator O is given by

$$< O >= \sum_n |b_n|^2 (\bar{\phi}_n, O\bar{\phi}_n) / \sum_n |b_n|^2 \qquad (19)$$

(17) and (19) show that we have incoherent states $\bar{\phi}_1, \bar{\phi}_2, etc$ once averages over time intervals for the phases c_n in (18)vanish owing to their relative randomness. Here while the state ϕ_N in (16) represent the Planck oscillators, the states $\bar{\phi}_1, \bar{\phi}_2 etc.$ in (17) or (19) represent the energy states of elementary particles, which averageover 10^{40} Planck oscillator states.

4 Conclusion

We have thus argued from different independent points of view that an underpinning of Planck oscillators in a background of Dark Energy explains in a thermodynamic sense, why the universe settles at the real life elementary particle scale rather than the Planck scale.

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